australasian (iron & steel) slag association

QUICK REFERENCE GUIDE 1 - 2013

Roads Guide Supplement on General Applications

1. INTRODUCTION

The continuing need to preserve diminishing natural resources and increase sustainable practices is a fundamental tenet in business today. This has predominantly occurred through the promotion of increased reuse, recycling and reprocessing. Here, disposal has become the last resort and is an issue of great importance in our society.

This focus on the importance of preservation and resource recovery is supported by international, federal, state and local Governments with respective regulating authorities empowered to ensure these sustainable goals are met through effective policy implementation.

The use of iron and steel slags (ISS), being a co-product of iron and steel production, are predominant in road construction and maintenance applications. These large-scale applications provide for the large-scale recovery of an abundant product which demonstrates the goals of sustainability.

With the formation of the Australasian (iron & steel) Slag Association in 1990, there has been a number of significant changes and advances in the effective utilisation of slag materials. Effective utilisation is the use of slag materials in a productive or economically beneficial way which does not require disposal as landfill. The vast majority of ISS produced in Australia is sold for use in today's market.[1] For example, in 2010, 88% percent of the 2.67 million tonnes (Mt) of ISS produced was effectively utilised within various value added civil and construction material applications throughout Australasia. The key results include:

- 33% consumed in high value add cementitious applications
- 50% delivered into road construction and civil works

During the 1990s, effective utilisation of ISS remained at 30-40%. However, current utilization rests at around 85%, illustrating changing paradigms in the active reuse of these products.

Collaborating through the Association in 'doing together what we could not do alone', we have broadened both stakeholder and community understanding. This now extends to material users, specifically those in road construction which has led to further increases in effective utilisation.

Slag co-products are the result of highly controlled steel-making processes. Therefore, these materials carry the same level of quality as the result of these process controls, which ensure the consistency of slag chemistry and quality.

The types of slag covered in this guide are:

1) Blast Furnace Slag (BFS)
   i. Granulated Blast Furnace Slag (GBFS)
   ii. Ground Granulated Blast Furnace Slag (GGBFS)
2) Steel Furnace Slag (SFS)
3) Electric Arc Furnace Slag (EAFS)
4) Ladle Furnace Slag (LFS)

Table 1 - Typical values for the physical properties of iron and steelmaking slags.[2]

Physical Property - Aggregate	Blast Furnace Slag	Steel Slag		Test Method
	Rock Slag	BOS Slag	EAF Slag	
Bulk Density (t/m³) (loose)	1.2	1.7	1.7	(AS 1141.4)
Dry Strength (kN)	100	250	250	(AS 1141.22)
Wet Strength (kN)	90	220	220	(AS 1141.22)
Wet/Dry Variation (%)	10	12	12	(AS 1141.22)
Water Absorption (%)	5	fine - 3.0 coarse - 2.0	fine - 3.0 coarse - 2.0	(AS 1141.5/6)
LA Abrasion	40	15	16	(AS 1141.23)
Polished Aggregate Friction Value (PAFV)	50	55	60	(AS 1141.41/42)
Sodium Sulfate Soundness (%)	<1.0	<1.0	<4	(AS 1141.24)
Physical Property- 20mm Road base				
Maximum Dry Density (kg/m³)	2,200	2,200	2,250	(AS 1289.5.1.1)
Optimum Moisture Content (%)	10	11.0	10	(AS 1189.5.1.1 & AS 1289.2.1.1)

Note: - ¹OMC depends on the components of the mix.

2. METHOD OF MANUFACTURE

Slag is a co-product of all common steel production methods. Here it forms either through the addition of fluxes such as lime or as the oxide portion of iron ore. There are a number of different slag types produced which is dependent on the steel-making process used. Table 1 outlines typical physical properties of ferrous slag produced in Australia.

2.1 BLAST FURNACE SLAG (BFS)

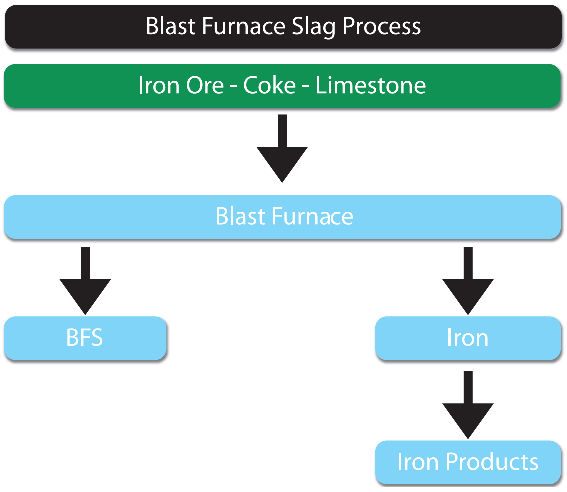

Figure 2.1 - BFS Manufacturing Process.

BFS is produced when iron ore is reduced to iron in a blast furnace. Molten slag from the furnace is poured into pits and allowed to cool in air. Rock like minerals are formed which are then crushed and screened to separate them into aggregates and sands.

Air cooled blast furnace slag materials are grey, vesicular rocks slightly lighter in weight than natural materials like basalt.

2.2 GRANULATED BLAST FURNACE SLAG (GBFS)

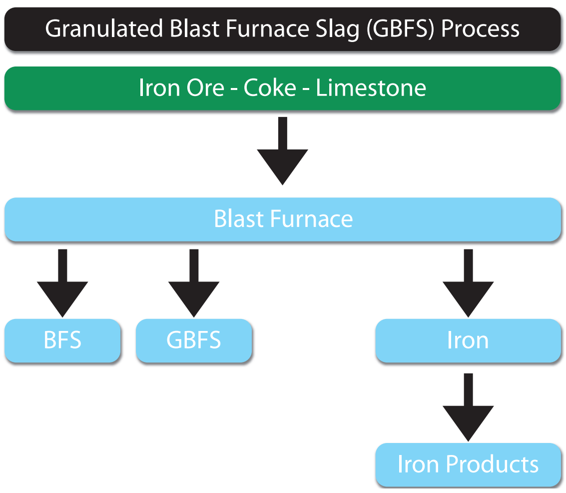

Figure 2.2 - GBFS Manufacturing Process.

GBFS is produced when molten BFS is rapidly quenched by a series of high pressure/high volume water sprays. These conditions cause the slag to solidify before crystallisation is able to occur, creating a glassy material.

GBFS is similar in appearance to river sand with a density of 60-70% that of natural sand.

2.3 GROUND GRANULATED BLAST FURNACE SLAG (GGBFS)

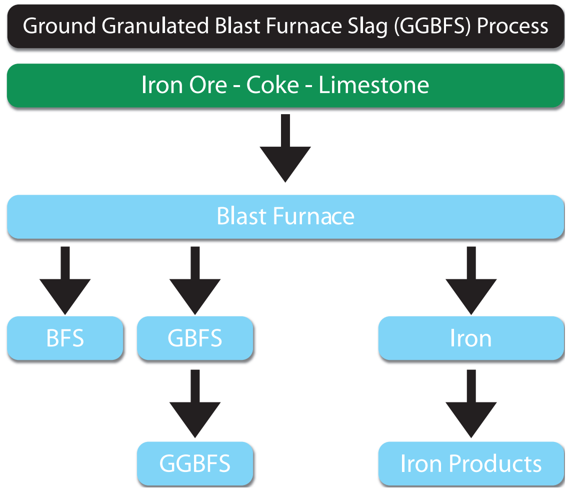

Figure 2.3 - GGBFS Manufacturing Process.

GGBFS is produced when GBFS is ground to cement powder fineness in a ball or vertical roller mill and has an off-white colouration.

2.4 STEEL FURNACE SLAG (SFS)

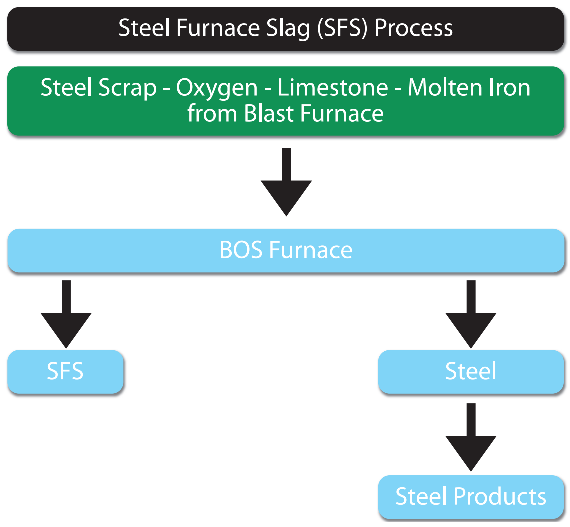

Figure 2.4 - SFS Manufacturing Process.

SFS is a co-product of the conversion process of molten iron to steel in a basic oxygen steelmaking shop within an integrated steelworks. Where the violent reaction occurs within the vessel after the oxygen lance is lowered, a protective slag layer forms with the addition of lime. When the reaction has been completed, the steel and slag are separated and molten slag is poured into pits where the slag is cooled with waters sprays after initial solidification.

SFS has a dark grey colour, with a particle density that is 20% greater than basalt and is definitively harder than BFS. This product crushes into a cubical shape and has the potential for expansion if not adequately weathered.

Weathering is typically achieved by periodic watering, monitoring and internal stockpile management procedures.

2.5 ELECTRIC ARC FURNACE SLAG (EAFS)

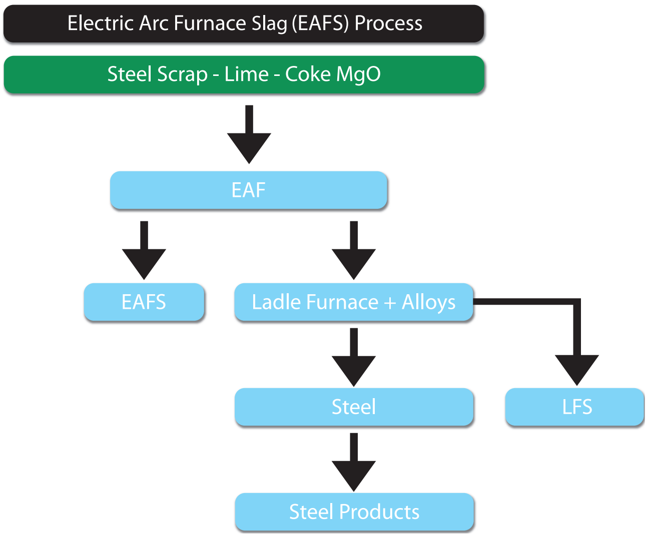

Figure 2.5 - EAFS Manufacturing Process.

As the molten slag is produced, it is tapped directly into adjacent pits and begins to solidify in air. This product then undergoes a further refinement process to remove the residual metallics and remaining slag, which is then separated into various product streams.

As a co-product of the steel making process, EAFS is produced in an electric arc furnace. In terms of its physical appearance, the slag is dark grey in colour and harder than BFS with a particle density of 20-25% greater than basalt. This product crushes into a cubical shape and has the potential for expansion if not adequately weathered. Weathering is typically achieved by periodic watering, monitoring and internal stockpile management procedures.

2.6 LADLE FURNACE SLAG (LFS)

Refer to **Figure 2.5** for the diagram of the manufacturing process.

LFS is a co-product of the Ladle Metallurgy Furnace (LMF) process which is the refining process of liquid steel sourced from the EAF, but prior to casting. After the EAFS process has occurred (see Figure 2.5) and most of the EAFS removed, the liquid steel is tapped from the EAF into a ladle. The ladle of liquid steel is then alloyed at the LMF to achieve the required chemical specifications. After specification is achieved, the liquid steel is poured out during casting and the remaining LFS is retained to be poured out separately, cooled, and then reprocessed to recover metallics.

The composition of LFS varies depending on the EAF, ladle furnace processing conditions and the type of steel grade being produced.

2.7 CURRENT STANDARDS

Quality assurance principles, as seen in Table 2, are in place to ensure the supply of high quality, safe, reliable and uniform ISS products to the market place. Under these standards, slag products are used to substitute or supplement naturally won materials to maximize natural resource sustainability, minimise waste to landfill and improve construction and manufacturing processes.

Table 2 - Quality Assurance Principles.[3, 4, 5, 6, 7]

Application	Principle
Road Base	Heavily Bound: NSW RMS R73 and various Council specifications
	Unbound: RMS 3051 Austroads, ARRB SR41 and various Council Specifications
Fill	Select Fill: NSW RMS 3071 and various Council specifications
	General Fill: RMS R44 and various Council specifications

3. TYPICAL CHEMICAL

The typical chemistry of BFS, SFS, EAFS and LFS after appropriate conditioning and weathering is shown in Table 3 below. All ISS comply with the necessary guidelines for their chemical composition.

Table 3 - Typical Chemical Characteristics.[8]

Constituents as Oxides	Symbol	BFS (%)	SFS (%)	EAFS (%)
Calcium Oxide	(CaO)	41	40	35
% Free Lime		0	2	1
Silicon Oxide	(SiO_2)	35	12	14
Iron Oxide	(Fe_2O_3)	0.7	20	29
Magnesium Oxide	(MgO)	6.5	9	9
Magnesium Oxide	(MnO)	0.5	5	6
Aluminum Oxide	(Al_2O_3)	14	3	6
Titanium Oxide	(TiO_2)	1	1	0.5
Potassium Oxide	(K_2O)	0.3	<0.5	0.1
Chromium Oxide	(Cr_2O_3)	<0.005	0.1	1
Vanadium Oxide	(V_2O_5)	<0.05	1.4	0.3
Sulphur	(S)	O.6	<0.1	0.1

4. ENVIRONMENTAL

Australia's adopted environmental policy holds closely to the precautionary principle without regard or recognition of the considerable scientific evidence gathered over the past 30 years.[8]

National environmental legislators and regulators have been hesitant in adopting more progressive and modern international approaches that incorporate sustainability objectives. Despite definitions and traditional categorisations which have kept slag labeled as a 'waste' material,[9] our members have explored and developed innovative, value-adding options for ISS to rebut these restrictions.

In recent years, National and State Environmental Departments and Agencies, as part of an overall review of the classifications of 'wastes' have progressively implemented changes to simplify and streamline the current waste classification systems.

Through these systems, the Association has been instrumental in negotiating and securing various exemptions or approval pathways for ISS materials including:

- Blast Furnace Slag including, Granulated Blast Furnace Slag
- Steel Furnace Slag
- Electric Arc Furnace Slag
- Ladle Furnace Slag

These exemptions represent a significant and important step towards creating greater investment certainty for our industry members.

Exemptions may be used by anyone, without seeking approval from the EPA, provided the generators, processors and consumers fully comply with the conditions of the exemption. However, these exemptions do not excuse those using them from complying with relevant planning consent requirements and it is their responsibility to seek any necessary development consents from the appropriate regulatory authority.

General exemptions are developed and published by NSW EPA with input from industry groups for materials which can be recovered, reprocessed or reused. These exemptions can be used without notifying the granting authority provided that the conditions of the Exemption are met. For example, conditions that are prescribed in the General Exemption give guidance for end use applications 'such as' concrete. This is not to mean only concrete but applications that result in bound matrices, for example, bound pavement products like slag road base.

General exemptions are gazetted as they become available or when the exemption is amended or revoked. Resource Recovery Exemptions can be amended from time to time and generators, processors or consumers of waste derived materials should reference the website for the latest versions.

Copies of NSW EPA exemptions gazzetted for iron and steel slags can be downloaded from: http://www.epa.nsw.gov.au/waste/generalrre.htm

In recent years, increasing awareness of environmental issues in our society has improved utilisation of slag. For example, carbon reduction opportunities through the use of slag have been tried and tested as a sustainable alternative which gives preference to this material in comparison to the use of traditional cement and quarried resources.[10, 11] When coupled with member companies identifying new opportunities for slag products, investment will continue to ensure these markets are further developed.

5. CASE STUDIES

There are numerous case studies, which demonstrate the effective utilisation of slag. The following case studies are a selection of recent projects where ISS provided solutions for the project contractor, proponent or client.

Table 4 - Case Studies in NSW.

Application	Amount of Slag Used (kt)
North Kiama By-Pass	165
Lake Macquarie City Council various projects	80
Princes Highway Realignment Oak Flats	70
Hunter Expressway NSW	68
Wollongong Northern Distributor Extension	40
RTA/RMS various projects Greater Newcastle NSW	31
Gosford City Council various projects	22
New England Highway, Harpers Hill NSW	16

5.1 CASE STUDY 1: NORTHERN DISTRIBUTOR EXTENSION, BULLI NSW

In 2009, construction commenced on the Princes Highway Northern Distributor Extension linking Wollongong to the northern Bulli area.

The main slag product used was an 80:20 ratio of air-cooled BFS:GBFS with 2% binder. In addition, 300 mm of BFS select fill and a 600 mm fines layer of air cooled BFS was used in the sub base.

BFS road base was the preferred material proposed under tender. This material was preferred over natural equivalents because of its reduced compactive effort and increased life expectancy as a result of strength gain over time.

Over the period of March 2009 until November 2009, 40 kt of BFS material supplied to the project. This material complied with RMS specifications R73 and 3051.

Figure 5.1 - Northern Distributor heading north.

5.2 CASE STUDY 2: NORTH KIAMA BY-PASS, SOUTH COAST NSW

The Kiama by-pass commenced construction in 2005 with a significant amount of slag used over a large area.

Figure 5.2 - Truck unloading slag material at site.

The types of slag used depended on the specific area on which the road traversed. In one section, 75 mm of air cooled BFS was used as a drainage layer. The area closest to Bombo beach required 300 mm of modified road base with an 80:20 ratio of air cooled BFS:GBFS with 2% binder.

Figure 5.3 - Aerial view of completed project.

Once again, BFS was the preferred material and from January 2005 until October 2007, 165 kt of BFS stabilized road base was supplied which complied with RMS specifications R73 and 3051.

5.3 CASE STUDY 3: HUNTER EXPRESSWAY HEA, NEWCASTLE NSW

In 2011, 67 kt of slag material was supplied to the Hunter Expressway in the form of heavily bound pavement and heavily bound, high load bearing hardstand material.

During this process, the Specific RMS specification RN73 “Ed 6 Bound Pavement Course (Slag or Ash based)” and the relevant EPA waste regulation specific exemptions have been conformed to.

The SFS and EAF slags are sourced from the Port Kembla, Rooty Hill and Newcastle steel-making operations.

Once delivered to the manufacturing facility, the SFS and EAFS is blended with other constituent materials in a computer controlled process to produce a heavily bound pavement material.

The stabilised road base material is placed and compacted using a combination of proven civil construction methodologies and ongoing best practice in the use of slag based materials for civil construction purposes.

This material has been used in a number of applications including:

- Heavily Bound Pavement: Construction of new heavily bound traffic pavements meeting RMS specification RN73 Ed6.

Figure 5.4 - Heavily Bound Pavement.

- Mine Void Platforms: Existing mining voids underneath the Hunter Expressway alignment required filling to minimize the risk of mine subsidence. Slag material is a preferred material to the emplacement of unbound road base due to the increased production capacity, a safer working environment for personnel on the ground due to a stable ground covering and a decreased program due to weather tolerance.

- Access Tracks and Platforms for Bridge Works: Most of the 23 bridges used a 200-300 mm thick layer of BFS and SFS stabilised road base as a piling platform. The advantages of using this material include decreased run off and erosion and minimal costly piling delays.

Figure 5.5 - Hunter Express way piling works at bridge BW13 on a layer of stabilized road base.

In summary, the slag materials used added to the overall efficiency of the Hunter Valley Expressway project.

6. CONCLUSIONS

In terms of its competitive advantages in relation to other materials, ISS products have been proven for use in various types of applications including: cement and concrete manufacture, civil works, road construction, rehabilitation and stabilisation of existing roads, car parks and pavements.

Economically, ISS are comparative to other traditional resources, but should be assessed on a case by case basis given the other performance and environmental advantages.

The Australasian (iron & steel) Slag Association will continue to advocate for the current and potential uses of slag products as well as improving regulatory understanding of the benefits arising from slag use.

REFERENCES

1. http://www.asa-inc.org.au/annual-membership-reports.php (2012)

2. Australasian (iron & steel) Slag Association (2002), A Guide to the Use of Iron and Steel Slag in Roads: 2nd Revision, Wollongong, IHG Design (with amendments)

3. NSW RMS, R73, http://www.rms.nsw.gov.au/doingbusinesswithus/specifications/roadworks.html

4. NSW RMS, 3051, http://www.rms.nsw.gov.au/doingbusinesswithus/specifications/materials.html

5. ARRB, SR41, http://www.arrb.com.au/Information-services/Publications.aspx

6. NSW RMS, 3071, http://www.rms.nsw.gov.au/doingbusinesswithus/specifications/materials.html

7. NSW RMS, R44, http://www.rms.nsw.gov.au/doingbusinesswithus/specifications/roadworks.html2. Heidrich, C. (2010). A move towards legal certainty - changing the waste paradigm 6th Global Slag Conference and Exhibition, Sydney, Pro Publications.

8. Australasian (iron & steel) Slag Association (2002), A Guide to the Use of Iron and Steel Slag in Roads: 2nd Revision, Wollongong, IHG Design, p. 6 (with amendments)

9. Heidrich, C. (2010). A move towards legal certainty - changing the waste paradigm 6th Global Slag Conference and Exhibition, Sydney, Pro Publications.

10. Heidrich, C., I. Hinczak, et al. (2006). GGBFS lowering Australia's greenhouse gas emissions profile. Global Slag Conference, Bankok, Thailand, GBC.

11. Woodhead, A., C. Heidrich, et al. (2010). A sustainable supply chain approach to creating new EAFS product opportunities. 6th Global Slag Conference and Exhibition, Sydney, Pro Publications.

AUSTRALASIAN (IRON & STEEL) SLAG ASSOCIATION

Suite 2, Level 1, 336 Keira Street,
Wollongong NSW 2500 Australia

PO Box 1194
Wollongong NSW 2500 Australia

Telephone: +61 2 4225 8466
Fax: +61 2 4228 1777
Email: info@asa-inc.org.au